CONSTRUCTION METROLOGY STANDARDS IN ORBITAL FACILITY CONSTRUCTION, MAINTENANCE, AND OPERATION

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Abstract: Space based construction metrology has a great potential for monetary and effort savings through the creation and use of open industry standards to support construction automation in space. Current technology for construction automation in space requires either one vendor to provide an entire solution, or an organization, such as NASA, to coordinate the efforts of vendors in tightly integrated projects that lock vendors in for the life of a facility. Open space based construction metrology standards could provide a means to promote competition over the life of a facility by supporting interoperability. LiveView is being designed to meet the goal of construction metrology automation, and may be applicable to special issues arising in an orbital workplace.

Keywords: Automation, Construction, Metrology, Space, and Standardization.

1 INTRODUCTION

The congress having recently instructed the United State's National Aeronautics and Space Administration (NASA) to research commercialization of the International Space Station (ISS), NASA has the potential to open a new era of commercial interest in Earth orbit. With open standards in space metrology, automation of construction related tasks, maintenance, operations, and upgrades of the ISS could be handled using practices inspired by terrestrial construction and research projects.

1.1 Open Construction Metrology Standards

NIST is currently investigating terrestrial automated construction metrology and supporting standards [6]. Construction metrology standards enable management of the construction project to be handled by a construction management company. That management company integrates various sub-contractors to work on a project. A standard means of reporting metrology data relays information about the contractor's work to construction management.

The implications of quicker, automated metrology data on construction projects are lower overhead and more efficient construction project management. Construction visualization systems [7], teleoperation, and computer-assisted task planning all could enable more effective management by offering more timely information.

An aspect of management is the ability to communicate with subordinates. A construction management company dealing with proprietary interfaces to autonomous construction equipment would suffer an integration nightmare, even with a small number of interfaces. In orbit, this is confounded due to limited potential vendors, who could use their presence in orbit to force acceptance of their proprietary system. The concept of a construction metrology standard is that all vendors could communicate the results of their actions. With one interface, integration of incoming data to a management database becomes feasible. In fact, in the event that vendors must be swapped during the construction phase, the single interface allows the seamless switch.

2 ISSUES FOR SPACE APPLICATION

Even today, proposed projects in space call for robotic automation in projects such as the International Space Station [1] and the Space Solar

Power Initiative. If the ability to interchange different robots from different vendors to accomplish similar tasks is desired then standards for interoperability are necessary. In addition to a framework for the physical integration of robots on facilities, current standardization being done by NASA for the ISS [1], an open metrology standard is necessary. This standard would enable these robots to report their operational status and any metrology they sense related to the facility. Additionally, maintenance agents could use such standard reporting over the potentially long life of the facility.

Construction robots in space will need construction metrology data. Data about the state of the construction site, location and quantities of components, and the status of activities of other robots (which cannot be assumed to be reliable) are all included as part of the metrology data that needs to be measured [9]. Terrestrially, surveying and inventory control are examples of basic tasks that generate metrology information.

For terrestrial construction projects, where humans provide most of the labor, the means of communications are fairly straightforward. Sketches, diagrams, inventories, blue prints, and more make up the standard means to communicate between the surveyors and inventory control managers (the two provide metrology data) and the human workers. In most terrestrial projects, automation of construction is non-existent.

However, in orbit, even the nature of the data to be collected for metrology purposes is different. An old Newtonian rule states "objects in motion, stay in motion unless acted upon by an outside force; objects at rest, stay at rest". Terrestrially, this translates to most components in a construction site being "at rest" on the ground and stationary. In orbit, however, objects are rarely at rest, even if addressed in a local frame tied to a common base reference within a work site. Addressing the location of a group of components as a trajectory in relation to the site may be important to ensure that the components do not leave the vicinity of the orbital construction site. Thus, the trajectory information for the site and components, as well as the robots, is necessary for a complete picture of the dynamic state of an orbital construction site [9].

Humans do most terrestrial surveying; in space there is a need to automate as much as possible, as human time for extra-vehicular activity is a limited and expensive resource. As well, extra-vehicular activity is dangerous for humans. Although teleoperation may solve the need for direct human action [10], the operator should have access to as much information as possible to aid teleoperation. A standardized means of collecting metrology data is needed to be able to integrate data from multiple sources, potentially provided by different vendors. An example would be one vendor's system that provides location information about discrete items on a construction site and another vendor's robot system that might be able to act temporarily as an observer of the operation of a third vendor's robot being teleoperated for an assembly task.

Although having the sensory data available to all robots, or human teleoperators, is a boon; sharing a global model of the world is even more valuable. Consider transmitting the change of location and orientation of an object in a model of the world, as opposed to a raster range image of the scene that contains the object. Location and orientation in three-space can be represented with six real valued numbers. A raster image, however, could consist of thousands of points. Bandwidth is another scarce resource that must be allocated in orbit; special attention must be paid to intelligently communicate.

Maintenance tasks over the life of a facility could conceivably involve replacing maintenance robots. However, as the life of most facilities (terrestrial facilities at least) is measured in decades, it is possible that when a robot fails, a vendor of a specific robot may not exist any longer, not be desirable for some arbitrary reason, or another robot model may be more desirable. An open standard for interoperability enables new robots to be acquired to accomplish the task of the now defunct robot. Since the standard is open, the standard can be referenced as a requirement in a public bid for proposals.

In the past, single companies provided proprietary solutions for space application. Proprietary total solutions would tend to lock in a single corporate total solution provider. In a more openly competitive model, an overriding standard for data exchange could enable separate vendor robots to different each portion of the solution.

3 PROPOSED SOLUTION

At NIST, we are developing a new framework for interoperability and data exchange, LiveView. Simply put LiveView is a set of methods and standard practices to migrate data from producers (sensors) through one or more data processes to consumers (visualization, autonomous system, etc.). Figure 1 shows the four major components of LiveView: Sensing and Control, Network, Application Framework, and Model.

Figure [1] – LiveView is comprised of 4 interconnected areas

3.1 Sensing and Control

Exploring standard ways to represent sensors, actuators, and other state devices is a hard task. One must represent many types of information about sensors, such as, unique identity, uncertainty, and a sensor's state and it's results.

One potential solution is to utilize IEEE 1451[3], Standard for Smart Transducer Interface for Sensors and Actuators – Network Capable Application Processor Information Model. IEEE 1451 enables unique identification of transducers, network communication, and object models to operate transducers.

3.2 Sensor networking

Although it may seem trivial at first glance, establishing a network standard for construction tasks is daunting. The course to take here is to specify the minimum functionality of the network in terms of behavior. IEEE 1451 [3] and the OSE Model [4] both provide a framework in which to formally describe network interfaces and behaviors.

3.3 Sensor fusion and data interpretation

This is the phase with which the construction management software developer will have to interact. This layer provides a framework similar to Microsoft Foundation Classes (MFC [11]) in that user applications provide logic and domain knowledge to map the sensory data arriving from the network to be able to update a model of the world.

What occurs in the LiveView framework is that user code is called by and calls functions and methods in the framework. For example, new data arriving from the network might cause the framework to call a user function to decide what to do with the data. In turn, after the user function has decided on a change to the model, the user function may call framework functions to store or share that model change.

3.4 Model Sharing

Although LiveView does not require strict model sharing, methods exist to store and retrieve information about a world model in a standardized fashion.

One option for model sharing over a network is a proposed protocol based on IEEE standard 1278, Distributed Interaction Simulation (DIS) – Application Protocols [2]. It adds standard methods of reporting sensory input into an IEEE 1278 based distributed system. This system may include several worker robots, teleoperators, remote viewers, and more. The main premise is that the protocol is designed to enable autonomy of agents in a distributed system while providing a common means of sharing agent-state information. Initially, attempts were made to extend solely IEEE 1278 to accommodate for the entire construction metrology tasks; however this method has been abandoned due to problems with reporting observations in IEEE 1278 [8].

DIS protocols are a well-accepted method for representing spatial and temporal information about dynamic, physical entities in a simulated world. The standard has extensions for reliable management and integration of live participants into a simulation. The Web3D consortium is addressing the issue of integrating DIS protocols with 3D graphical (VRML) browsers [5].

The basic units of communications between the agents are protocol data units (PDUs) similar in format to those already defined in IEEE 1278. LiveView, featuring standardized sensory PDUs, enables the sensory data to be sent to multiple separately designed applications, the manager's 3D display and the database. PDUs contain information in standard form, referenced to an agreed upon coordinate frame.

3.5 Extended example & demonstration

Prototype LiveView implementations have been demonstrated in action on sample terrestrial metrology tasks. Two tasks were demonstrated in these initial versions, visualizing the state of construction equipment and tracking discrete construction components.

In one demonstration, an ATV and robotic crane [7] were instrumented [explain how] and visualized on remote systems. In these tasks, position, orientation, and status information about each needed to be communicated. Figure 2 shows the visualization of a robotic crane with a live camera feed on the same monitor.

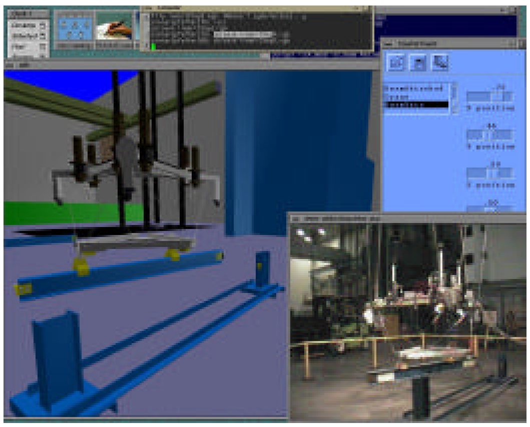

Figure [2] shows the visualization of a robotic crane. The inset video image shows the correspondence between the model and the real system.

The other application selected was to visualize the tracking of a discrete component, an I-Beam, at discrete times. In this task, a worker records cardinal point locations of the I-Beam using a position sensor, and tags the unique identity of that specific beam. The beam is moved, controlled again by the worker, and the visualization of the site is updated with the new location of the I-Beam.

Providing a common interface necessitates data abstraction is extremely important to make integration tractable. The instrumented ATV and crane dealt with passing location, orientation, and articulation information. Although making location and orientation interoperable might seem as obvious as fixing a global axis and rotation sequence, but a standard method for articulation is hard. IEEE 1278 specifies a means to express articulation, location, and orientation abstractly.

In the I-Beam tracking case, the concept of a point cloud was developed. In LiveView a point cloud is merely a number of location points in world coordinates. The worker annotates each reading to indicate which cardinal point has been taken, and which cardinal points are not taken. The worker's system then forms this abstract cloud of points and broadcasts this set of points on the network; the instrument used to take the points has been completely abstracted.

During the development of the software to record locations, two potential sensors were explored for use: Global Position Sensing (GPS) and Local Position Sensing (LPS - based on local beacons). Although the data reported by each system was similar, in that they both reported positions, the actual data was very different. The GPS reports data in WGS 84 format, while the LPS reports data in a local Cartesian coordinate system.

This problem was mitigated by abstracting both as point clouds and writing all support software to deal with the point clouds. In fact, the service to provide a globally registered location for the I-Beam was designed before the final sensor was selected.

At the same time the worker, the ATV, and the crane, are providing updates to the world model, a visualization application is displaying this modified model as soon as it receives the new information. For example, displaying a moved component or the movement of the ATV or crane.

In these activities there were several agents in the construction exercises. The physical agents are easy to identify; there is an ATV, a crane, an I-Beam, a LIDAR scanner, and a worker. Additionally, the visualization engine and the part location algorithm provided agent like activity in the system.

Other potential agents are a database to archive the observed change(s) in position of a component. Another agent could be an autonomous welder awaiting the placement of the I-Beam for installation.

This short example demonstrates potential in the tracking of components and robots in real time during construction. In orbit, where direct human access to the construction site might be limited or non-existent, systems that are capable of reporting metrology information about the site, such as LiveView will prove useful.

4 FUTURE WORK

The creation of a partial LiveView implementation that can be used to enable initial full-scale tests is an immediate goal. Such tests would be at construction sites employing a limited number of sensor systems for the purposes of tracking excavation and the erection of steel frame structures. Additional field tests of LiveView would be at an actual construction site.

Recommended practice documents for applying LiveView to construction automation and metrology tasks will be developed with special attention to remote management, as would be present in orbit, and other realms. These documents will provide system integrators with a complete picture of how a working system is put together. Additionally, such a document provides vendors of specific systems a model to follow for how their products could be used.

To further prepare LiveView for possible use in space applications, LiveView will need to move away from the Earth-centric position data standard used in IEEE 1278. Potential solutions include referencing position to several local position beacons that act as "corner stones" of the project (e.g. a central causeway of the station), or to the nearest celestial body and include detailed trajectory information. Further investigation of universal positioning beyond a narrow belt around the Earth's surface is needed.

Security issues, such as authority to see certain types of data, and safety will need to be addressed.

REFERENCES

URLs are current as of September 1st, 1999

[1] NASA, *Space Station Program Robotic Systems Integration Standards*, National Aeronautics and Space Administration, SSP 30550 Volume 1 Revision C Draft 8, 1998.

[2] IEEE, "IEEE Std. 1278-1a-1998, Standard for Distributed Interactive Simulations – Application Protocols," IEEE Customer Service, Piscataway, NJ 0855, (800) 678-IEEE, http://stdbbs.ieee.org/ (refers to 1995 ver.)

[3] IEEE, "IEEE Std. 1451, Standard for Smart Transducer Interface for Sensors and Actuators – Network Capable Application Processor Information Model", IEEE Customer Service, Piscataway, NJ 0855, (800) 678-IEEE, http://stdbbs.ieee.org/

[4] IEEE, "IEEE Std. 1003.0-1995, IEEE Guide to the POSIX Open System Environment (OSE)", IEEE Customer Service, Piscataway, NJ 0855, (800) 678-IEEE, http://stdbbs.ieee.org/

[5] Web3D consortium http://www.web3d.org/WorkingGroups/vrtp/dis-java-vrml/dis-java-vrml.html, mirrored at http://www.stl.nps.navy.mil/dis-java-vrml/

[6] Stone, W., Reed, K,. Chang, P., Pfeffer, L., Jacoff, A., "NIST Research toward Construction Site Integration and Automation," ASCE Journal of Aerospace Engineering, Vol. 12, No. 2, April 1999, pp. 50--57.

[7] Pfeffer, Lawrence E., "Wireless Networking for Integration of Real-Time Construction Metrology Systems," in the proceedings of the 14th International Symposium on Automation and Robotics in Construction (ISARC 14), Pittsburgh, PA, June, 1997.

[8] Pfeffer, Latimer, "Toward Open Network Data-Exchange Protocols For Construction Metrology and Automation: LiveView", 16th IAARC/IFAC/IEEE International Symposium on Automation and Robotics in Construction (ISARC), Madrid, Spain, Sep. 22-24, 1999

[9] Latimer, "Construction Metrology beyond Earth, A White Paper", 14th Space Studies Institute (SSI) Conference on Space Manufacturing, Princeton, New Jersey, USA, May 6-9, 1999

[10] Lunar Rover Initiative Home, http://www.frc.ri.cmu.edu/projects/lri/

[11] Blaszczak, "Professional MFC Visual C++", Wrox Press Ltd, Birmingham UK, 1997.